HINS Possibilities in Support of the Current Project X Design Concepts

Bob Webber

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Charge from Sergei

- Given the present direction of the Project X concept
  - What are the opportunities in using HINS as a test bench for PrX?
  - What could be the timeline?

Project X

Outline

- HINS traditional technical objectives
- Current status of the HINS program
- Present plans
- Re-evaluation given present direction of Project X
- The Big Questions
- Opportunities of what HINS can do for Project X
- A proposal with accompanying strategy
- A common thread
- Summary

HINS Program Traditional Goals

- Stated Mission - To address accelerator physics and technology questions for a new concept, low-energy, high intensity, long-pulse H- superconducting Linac; in particular, to demonstrate:
  - beam acceleration using superconducting spoke-type cavity structures starting at a beam energy of 10 MeV
  - multiple high power RF vector modulators controlling RF cavities driven by a single high power klystron for acceleration of a non-relativistic beam
  - beam halo and emittance growth control by the use of solenoid focusing optics
  - a fast, 325 MHz bunch-by-bunch, beam chopper

Recent Scope of HINS

- The components include:
  - 50 keV ion source (first protons, then H^-)
  - 2.5 MeV RFQ
  - MEBT with fast beam chopper system
  - 10 MeV “room temperature (RT)” linac composed of copper CH-type spoke accelerating cavities and superconducting (SC) solenoid magnets
  - One or two 9-cavity modules of 325 MHz, $\beta = 0.2$ SC spoke resonator (SSR1) cavities and SC solenoids operating at 4 °K for final 20 or 30 MeV beam energy
  - Two pulsed 2.5 MW klystrons to power the entire machine
  - A suite of beam diagnostics to characterize machine performance

Current Status

- Proton ion source is operational; H- source has been prototyped
- Beam has been accelerated through RFQ to 2.5 MeV
- Chopper development is incomplete and dormant
- Warm cavities are being RF conditioned to nominal power
- Warm section SC solenoid cryostats are being assembled
- First SSR1 cavity is welded into helium jacket
- Order for 10 SSR1 niobium cavities has been placed
- Test cryostat for full pulsed-power testing of jacketed SSR cavities is in place awaiting cryogenics connections
- SSR1 cryomodule design is just in its infancy
- Concrete block shielding enclosure scoped for the warm10 MeV section of the linac is under construction

Particular Comments on SSR Cryomodule Development

- The historical concept has been a cryomodule with nine cavities and nine solenoid magnets
- Design is not far advanced beyond that conceptual stage
- Issues include:
  - Component spacing - physical components do not accommodate spacing assumed in physics design of Proton Driver/HINS lattice
  - Component alignment tolerances and stability through cool-down
- Considerations for 2°K operation will be incorporated into the initial cryomodule design
- At either 4°K or 2°K, cryomodule design will be a major task
- Present wisdom suggests that constructing a prototype cryostat with fewer elements, which might also be used for the first SSR cavity beam demonstration, is advisable

Project X Near Term Plans – MDB Ops

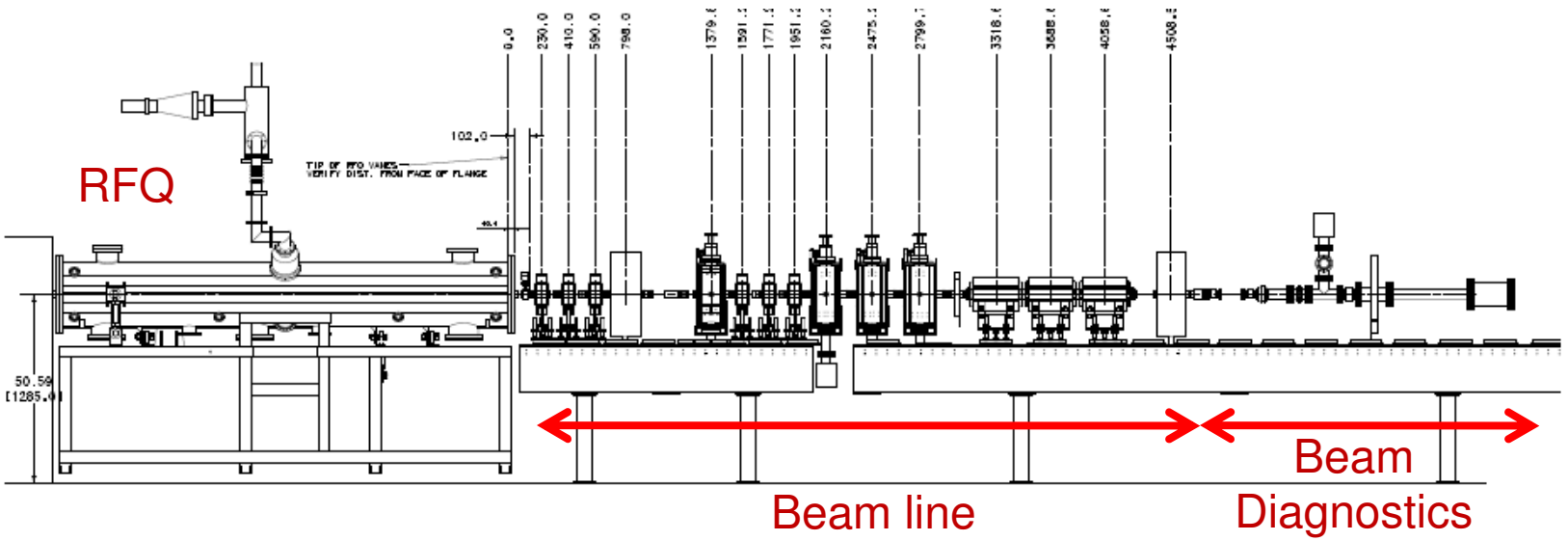
- 2.5 MeV Beam Operations
  - Maintain possibility to run 2.5 MeV beam from RFQ until ~mid-February
- RFQ
  - Remove from beam line to improve seals in cooling water tubing
  - ~10 weeks from removal to re-installation
- Linac Cave Construction
  - Continue construction of enclosure to support 10 MeV scope of operations
  - Complete with power and water utilities ~May?
- Superconducting Spoke Cavity Test Facility
  - Complete design and fabrication of cryogenic transfer line tubes
  - Cool down empty cryostat ~April?
- Complete HINS Safety Assessment Document, shielding assessment, and safety interlock system modifications for Linac enclosure and Cavity Test Facility Cave

Project X Intermediate Plans– MDB Ops

- Proceed in parallel with Cavity Test Facility efforts and with Linac beam tests
- Superconducting Spoke Cavity test facility –
  - Install first jacketed SSR1 cavity for CW testing in ~May 2010
  - Install same cavity dressed for first full-pulsed power test ~July 2010
- Beam operations –
  - Better characterize ion source beam while RFQ is being repaired
  - Re-install RFQ into beam line at suitable stage of enclosure construction; not before May 2010
  - Configure 2.5 MeV beam line for transverse beam emittance measurement after beam is re-established
  - Install “Six-Cavity Test” RF distribution system and subsequently beam line elements; ready for “Six-Cavity Test” ~November 2010

The Six-Cavity Test

- Purpose: early demonstration of beam acceleration with vector modulator control (before availability of cryogenics distribution system)
- Warm quadrupole magnets substituting for SC solenoids
- ~3.0 MeV protons
- Diagnostic line for beam evaluation



A Look at HINS Goals from Project X Perspective

- Beam acceleration with superconducting spoke-type cavity structures
  - 325 MHz SC spoke cavities and associated infrastructure development must be preserved and expanded for Project X
    - Fabrication and processing procedures
    - Spoke cavity testing facility
    - 325 MHz RF power
  - **Project X might benefit greatly from a first-ever test of acceleration of few-MeV beam through SC spoke cavities offered by HINS**
- 325 MHz high power RF vector modulators
  - Of the initial HINS goals, this is the earliest achievable (six-cavity test)
  - Associated 325 MHz LLRF development is directly applicable to Project X
  - **This development is unavoidable if HINS beam beyond 2.5 MeV is to serve Project X before construction of SSR0 cryomodule**

A Look at HINS Goals from Project X Perspective

- Solenoid focusing optics
  - Falling out of favor given present direction of Project X concept
  - **RT solenoids must be completed or substituted if HINS beam beyond 2.5 MeV is to serve Project X before construction of SSR0 cryomodule**
- Fast, 325 MHz bunch-by-bunch, beam chopper
  - Beam preparation and chopper are crucial to Project X
  - The driving force of this development defaults from HINS to Project X
  - **HINS can offer the possibility of suitable beam for developing and testing Project X chopper and beam preparation techniques**

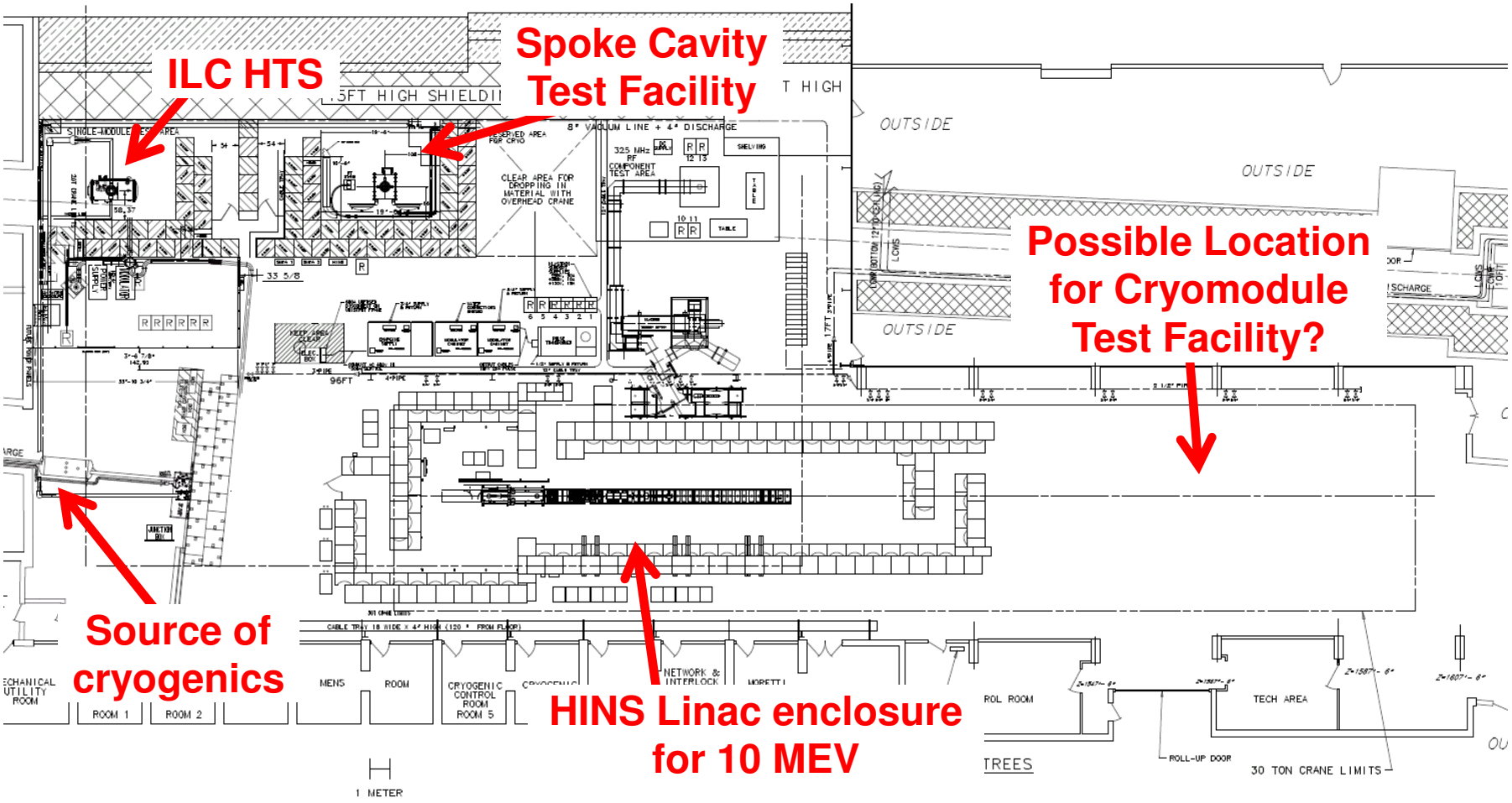
The Big Questions

- What characteristics of a flexible, pulsed low-energy beam facility are of most interest to Project X or other possible users?
  - For beam preparation and chopping performance verifications
  - For essential beam diagnostic instrumentation development and testing
  - For verification of simulation codes, esp. halo development and beam loss
- How valuable to Project X is the demonstration of beam acceleration through superconducting spoke cavities?
- In light of cryogenics demands, especially at 2°K, what is a sensible and affordable scope of facilities to consider operating at MDB?
- Does it make sense to continue the superconducting solenoid assembly (RT linac) and development (SSR linac)? (A decision now could save $)
- Should consideration of H^- ions be maintained in support of Project X2?
- What technical risks are acceptable in such a program?
  - 325 MHz klystron w/o spare?

Opportunities Using HINS as a Test Bench for Project X

- HINS offers a 325 MHz superconducting spoke cavity test cryostat
  - A jacketed spoke cavity does not fit in VTS at IB1
  - The cryostat is designed for 4° K, but upgradeable to 2° K, operation
- HINS offers the only source of high power 325 MHz RF at Fermilab
- HINS drives developments in 325 MHz LLRF and beam diagnostics
- HINS can offer suitable beam for
  - Demonstrating the viability of beam acceleration using superconducting spoke cavities
  - Testing beam chopper system performance
  - Developing and testing beam diagnostic instrumentation
- Pulsed beam through a SSR cryomodule powered by CW RF is a significant demonstration that might be possible at HINS MDB

Meson Layout



Cost Drivers

- Cryogenics plant capabilities and distribution in MDB
  - Distribution of 4°K fluids to HINS linac enclosure for solenoid magnets and SSR cryo module
  - Upgrade of plant to support any 2°K HINS operations
  - Distribution of 2°K fluids to?
    - Cavity test cave
    - HINS linac enclosure
    - Possible spoke cryomodule test facilty
- Manpower to design and install systems and provide support for test beam operations and to perform beam tests
  - This offers the benefit of maintaining a pool of talent close to beam operations.
- Management of this construction and operations program

Proposal for HINS Support of Project X

- Define phased objectives:
  1. Facility for testing individual superconducting spoke cavities
  2. Facility for testing beam preparation and chopping
  3. Facility for beam diagnostic instrumentation development and testing
  4. Demonstration of beam acceleration by superconducting spoke cavities
  5. Facility for superconducting spoke cryomodule testing

Objective 1 Strategy
Spoke Resonator Test Facility

- Proceed with superconducting spoke cavity test facility in MDB as presently planned
  - 4°K operation
  - Both pulsed and CW RF option
  - This will be operational in 2010
- When Project X freezes spoke cavity operating temperature and mode of RF operation (CW or pulsed)
  - Modify cryostat as required
  - Re-evaluate if MDB is the most effective location for the cavity test facility taking into account cryogenic plant requirements and RF power system considerations
- Integrate into overall MDB cryogenics plant/distribution plan

Objective 2 Strategy
Beam Prep & Chopping Facility

- Proceed with HINS Six-Cavity Test as presently planned
  - Drives developments required of any HINS beam ops beyond 2.5 MeV
    - Completion of HINS Linac shielding enclosure
    - Demonstration of vector modulator controlled system of RF cavities
  - Provides measurements useful to understand this beam and to configure a beam line to effectively support subsequent Project X tests requiring beam
  - Demonstration of accelerated beam through system of vector modulator controlled cavities expected by spring 2011
- As Project X defines beam preparation and chopping requirements
  - Re-configure beam line design (optics and final energy) to effectively achieve test results most useful to Project X

Objective 3 Strategy
Beam Instrumentation Facility

- Proceed as per Objective 2 strategy
- Determine, with due consideration of Project X requirements, whether/when H^- beam shall be incorporated into the facility
- Consider opportunities for diagnostics instrumentation development and testing with planning for each/any beam line reconfiguration
- Beam instrumentation development and testing opportunities are available beginning now

Objective 4 Strategy
Beam Acceleration by SSR Cavities

- Immediately evaluate economics of sticking with HINS solenoid focusing vs. switching to quadrupole focusing to provide a beam for the SSR cavity acceleration demonstration
  - Estimate cost to complete RT sections solenoids
  - Cost of cryogenics delivery system in the context of MDB big picture
  - Cost and schedule of quadrupoles
- Define minimum useful beam energy to inject into SSR cavity and build HINS Linac accordingly – set requirements ~Oct '10
- Assume "short" cryomodule (2-3 cavities) for acceleration demo
- Establish cavity operating temp (2 or 4 °K) and RF mode (pulsed or CW) for the demo (not necessarily the Project X final choices)
- Integrate into overall MDB cryogenics plant/distribution plan
- Beam acceleration through SSR might be achieved by end of 2012

Objective 5 Strategy
Spoke Cryomodule Test Facility

- Establish requirements for a Project X spoke cryomodule test facility, accounting for cryogenic plant requirements and RF power system considerations
- Evaluate suitability of MDB for the site of this facility
  - Compatibility/synergy with cryogenics needs of other Objectives
- Integrate into overall MDB cryogenics plant/distribution plan
- Actual facility is likely needed after early 2013

Cost Drivers by Objective

- Objective 1 – Cavity Test Facility
  - Possible upgrade to 2°K operation
- Objective 2 – Beam Preparation and Chopper Test Facility
  - Beam system to accelerate/transport beam to suitably high energy, including possible cryogenics delivery systems
  - Specific beam preparation and chopper components and equipment
  - Specific beam diagnostic instrumentation
- Objective 3 – Beam Instrumentation Facility
  - Beam system to accelerate/transport beam to suitably high energy, including possible cryogenics delivery systems
  - Specific beam instrumentation devices and support equipment
- Objective 4 – Beam Acceleration in SSR Cavities
  - Beam system to accelerate/transport beam to suitably high energy
  - Second 325 MHz klystron or multiple smaller RF power systems if CW
  - Cryogenics plant and delivery systems
- Objective 5 – Spoke Cryomodule Test Facility
  - Cryogenics plant and delivery systems

A Common Thread

- Cryogenics systems are a major consideration for planning:
  - Superconducting spoke cavity test facility
  - Spoke cavity cryomodule test facility
  - Superconducting spoke cavity beam acceleration demonstration
  - Any HINS beam beyond ‘Six-Cavity Test”
- Project X decisions on cavity operating temperature and CW vs. pulsed RF mode will have a major impact on the required cryogenics systems for each of these facilities and operations
- The cryogenics systems represent a high-cost, long lead-time resource
- It is imperative that an integrated plan for MDB cryogenics plant/distribution requirements is developed in a timely manner to support whatever facilities are expected to function in that building

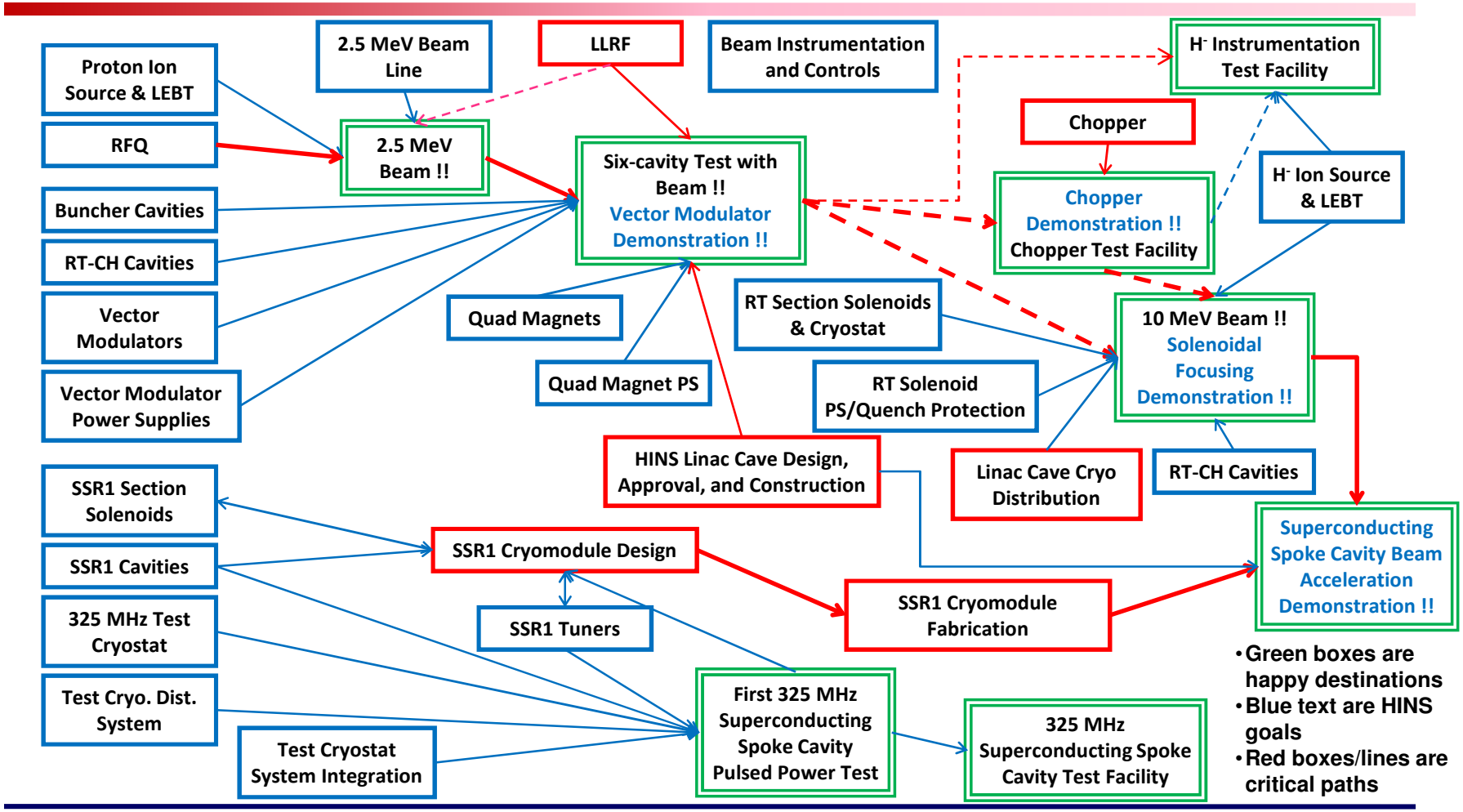
Summary

- HINS will provide a test cryostat for testing 325 MHz superconducting spoke cavities by late spring this year
- HINS will offer the possibility of 2.5 MeV beam in a shielded enclosure for Project X purposes by sometime this summer
- HINS will demonstrate, by means of the “Six-Cavity Test”, the ability to provide multi-MeV energy beam by spring 2011
- Pending development of an integrated cryogenics plant and distribution plan, HINS offers the possibility of:
  - Demonstrated beam acceleration through superconducting spoke cavities before 2013
  - A spoke cavity test facility upgraded for 2°K operation
  - A spoke cryomodule test facility
- Evaluation whether to continue solenoid effort should begin ASAP

Project X

Backups

HINS Strategy Roadmap



HINS Strategy

- Construct H^- linac to at least 10 MeV in pursuit of original HINS goals that remain relevant
- Build a beam facility for chopper testing and beam instrumentation development
- Continue SSR1 spoke cavity and cryomodule development activities with design considerations taken for CW and 2° K operation in direct support of Project X
- Achieve world-first beam acceleration through at least one SSR1 cryomodule operating at 4° K
- Continue SC solenoid design work as appropriate in support of above objectives

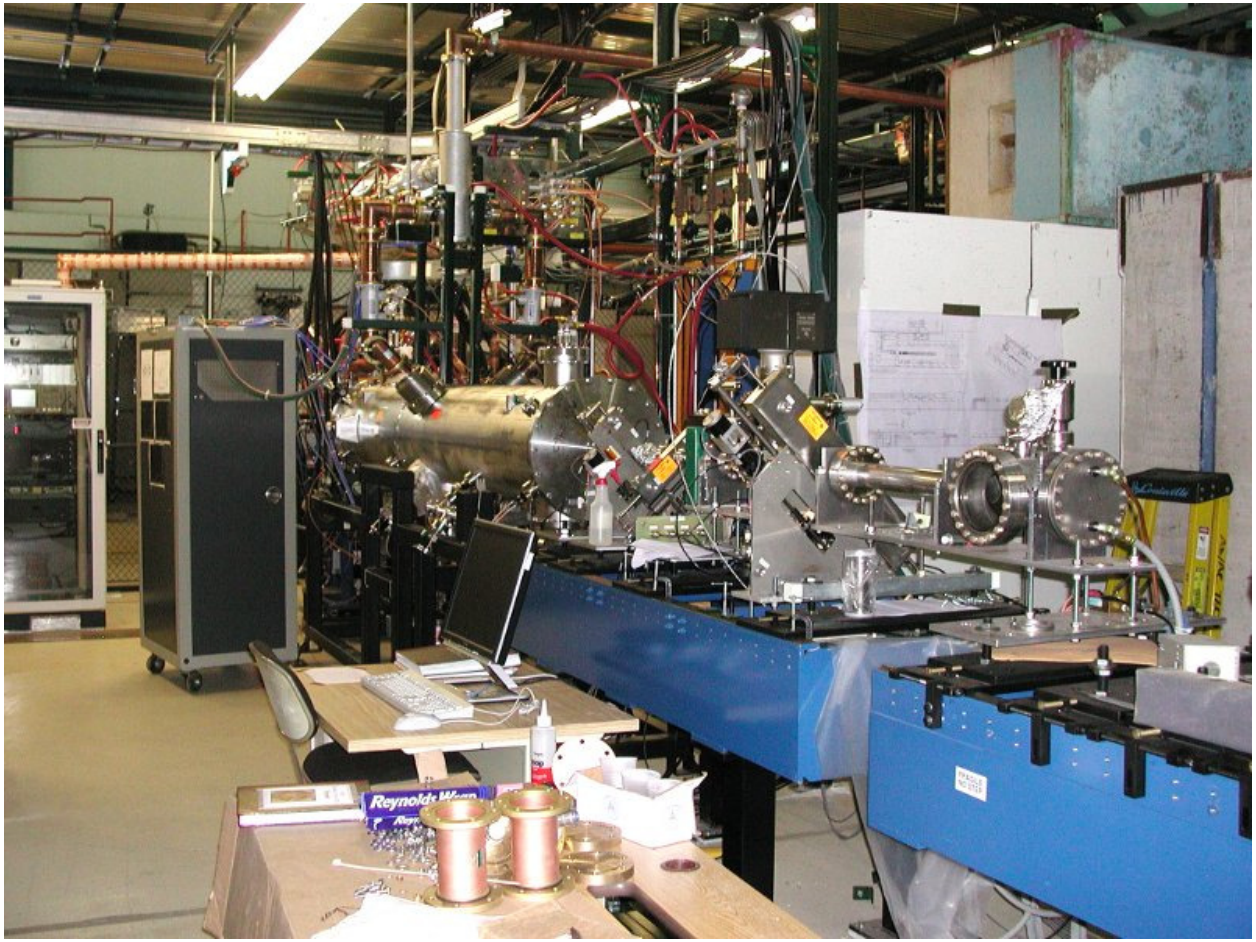
The Plan – Near Term

- Achieve beam from RFQ
- Install spoke cavity test cryostat and test cavity at full pulsed power
- Continue RT section SC solenoid and cryostat assembly work
- Procure an additional ten SSR1 niobium cavities
- Complete HINS Linac shielding enclosure
  - Initially sized to contain 10 MeV Linac, beam diagnostics line and absorber
  - Designed for easy extension to house up to two SSR1 cryomodules
- Complete full safety documentation
- Complete the “Six-cavity Test” for first vector modulator demonstration with beam
- Specify and design cryogenics distribution system for HINS linac

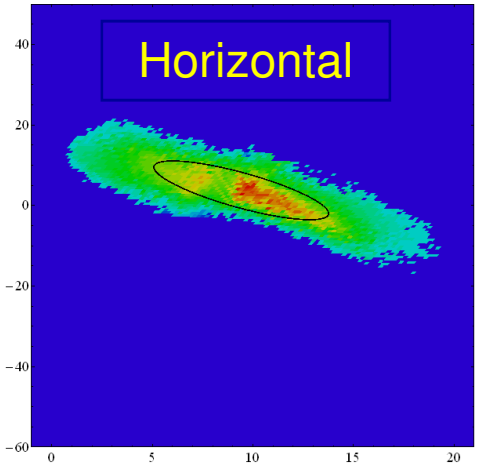
Conclusions

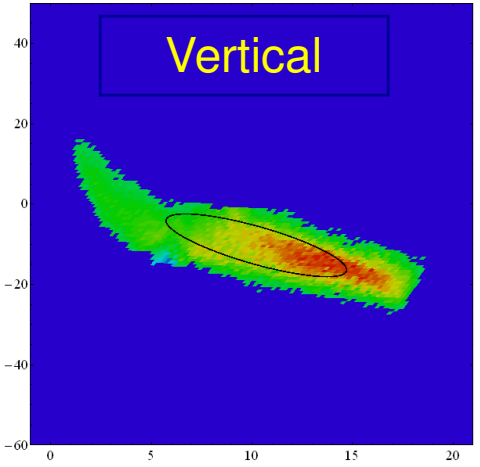
- Certain aspects of HINS, particularly 325 MHz SC spoke cavity development, are mainstream and vital to Project X
- Difficult to project how HINS supports Project X while the project definition remains in flux
- Need inputs as to what beam tests are most important to Project X
- There are issues accompanying a CW machine HINS is not well positioned to address in it present scope

RFQ and 2.5 MeV Beamline



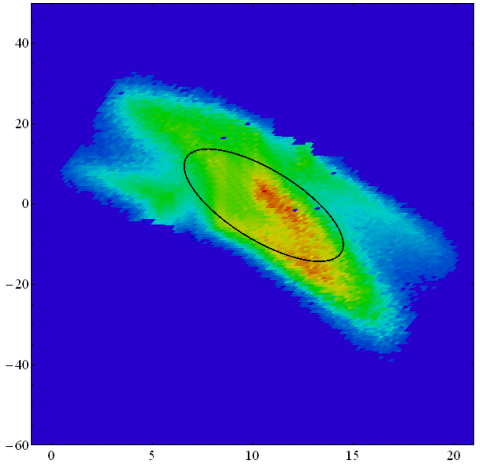
Typical Emittance Scan Data

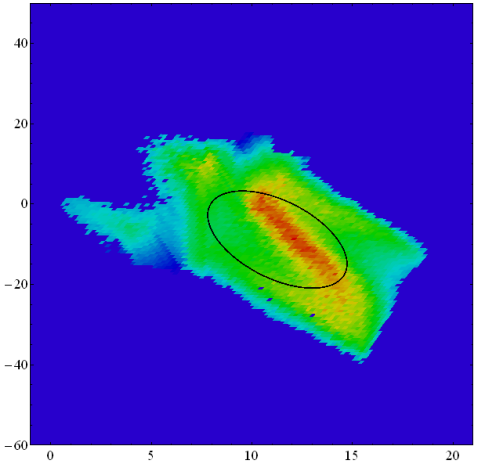




50 keV beam from HINS proton ion source

I_b = 4 mA

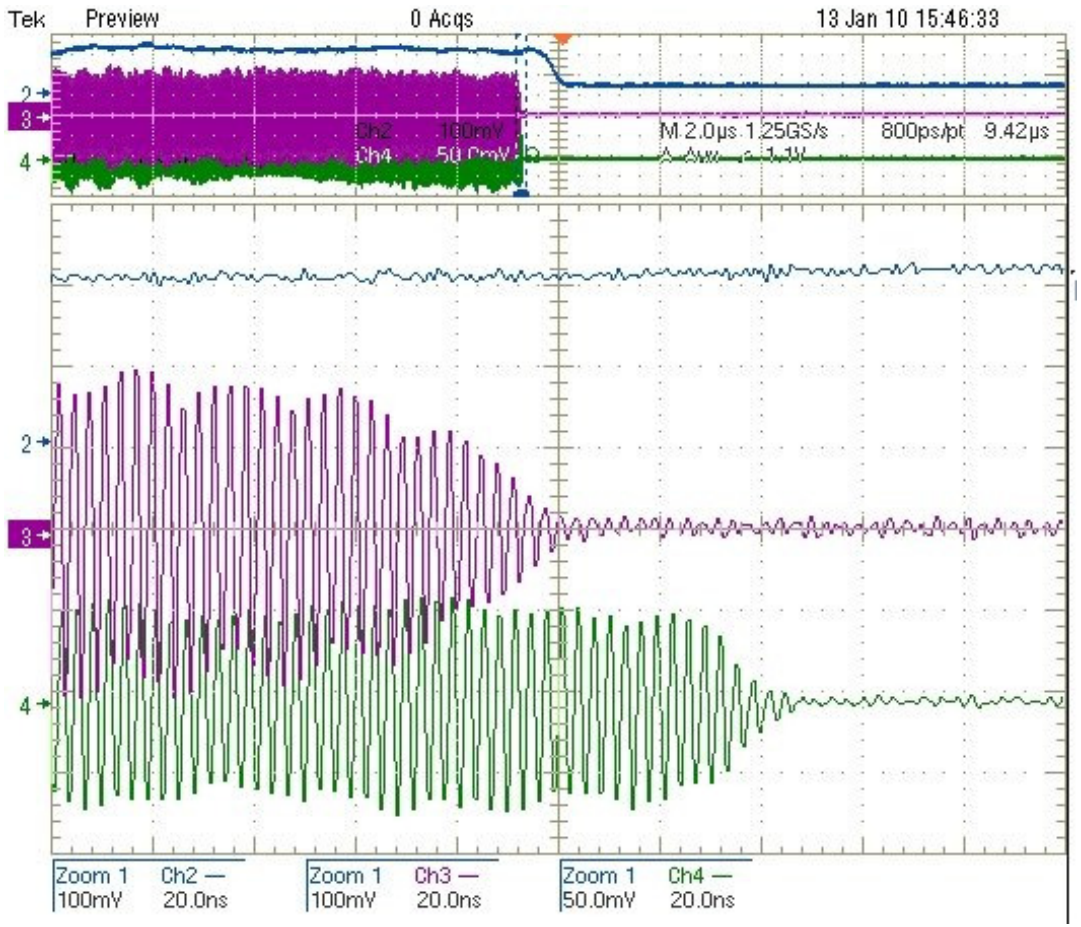




I_b = 12 mA

Plots by Wai-Ming Tam

Project X 2.5 MeV Beam through RFQ



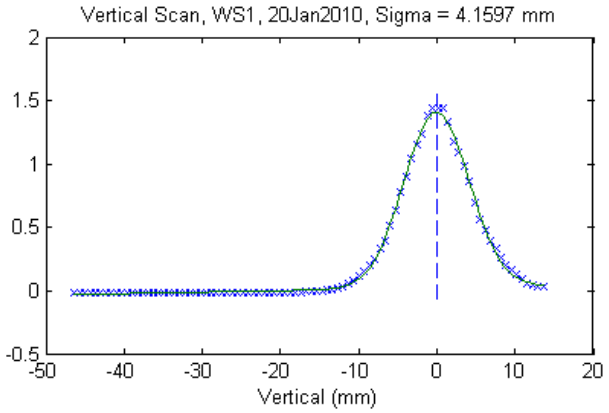
Signals from toroid and two BPM buttons, all downstream of the RFQ

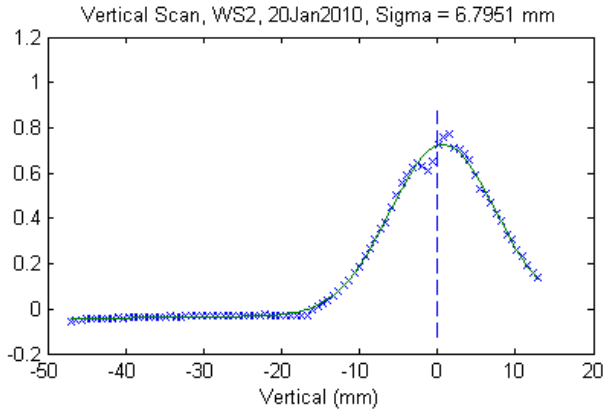
Upper display: 2 µsec/div
Lower display: 20 nsec/div

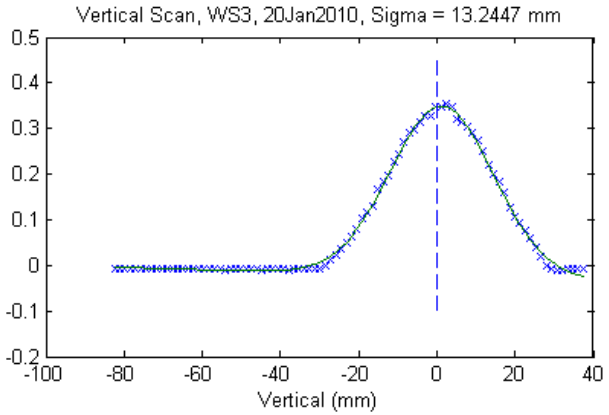
Lower display shows the 44nsec delay expected for transit of 2.5 MeV beam between the BPM two buttons separated by 0.96 meters

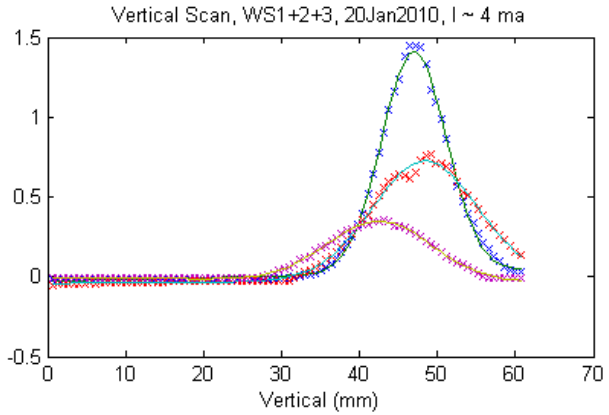
Beam current is about 3 mA

HINS 2.5 MeV Beam Profiles – Vertical at 4 mA

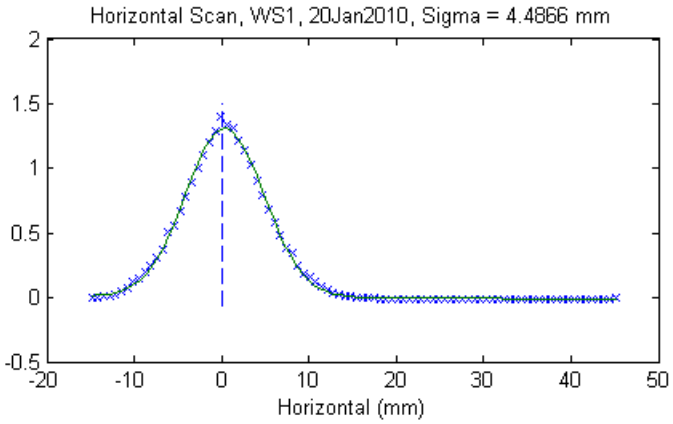


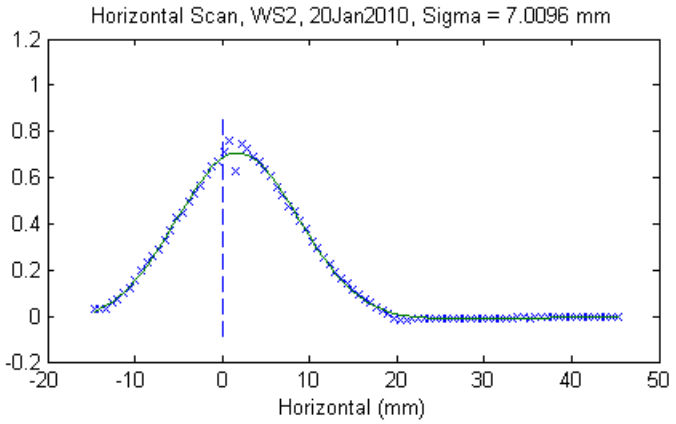


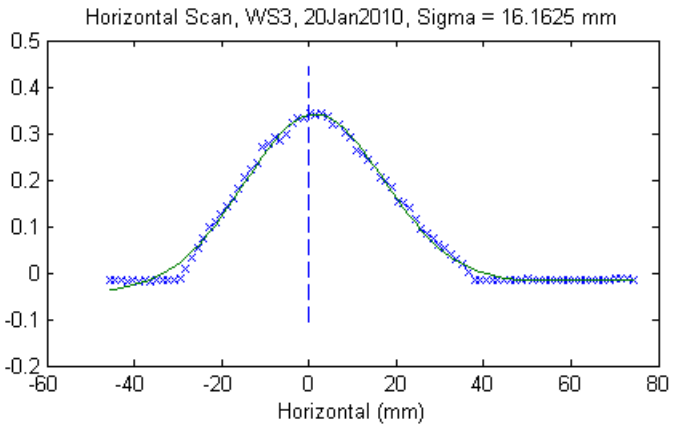


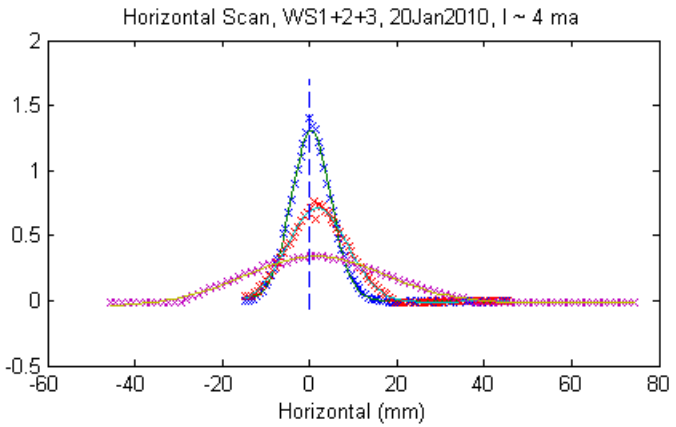


HINS 2.5 MeV Beam Profiles – Horizontal at 4 mA

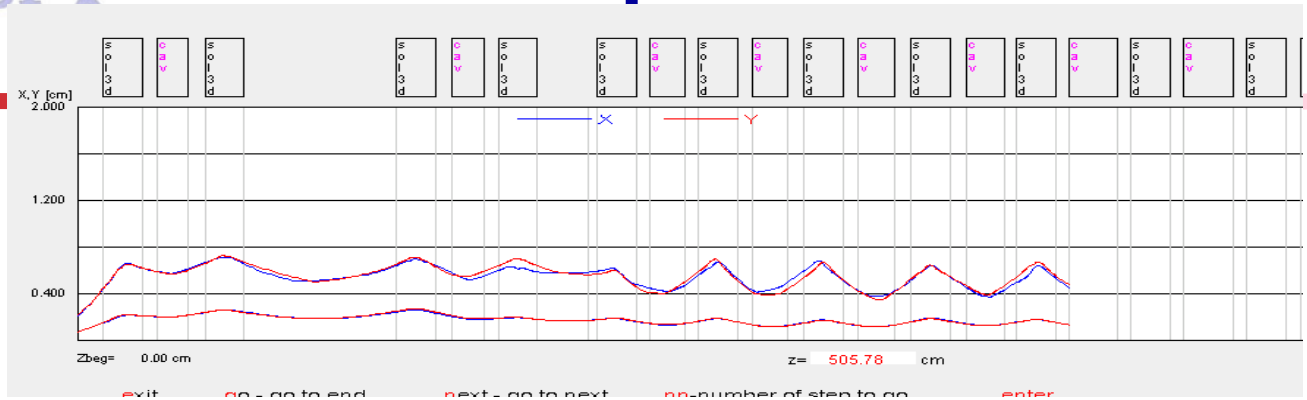


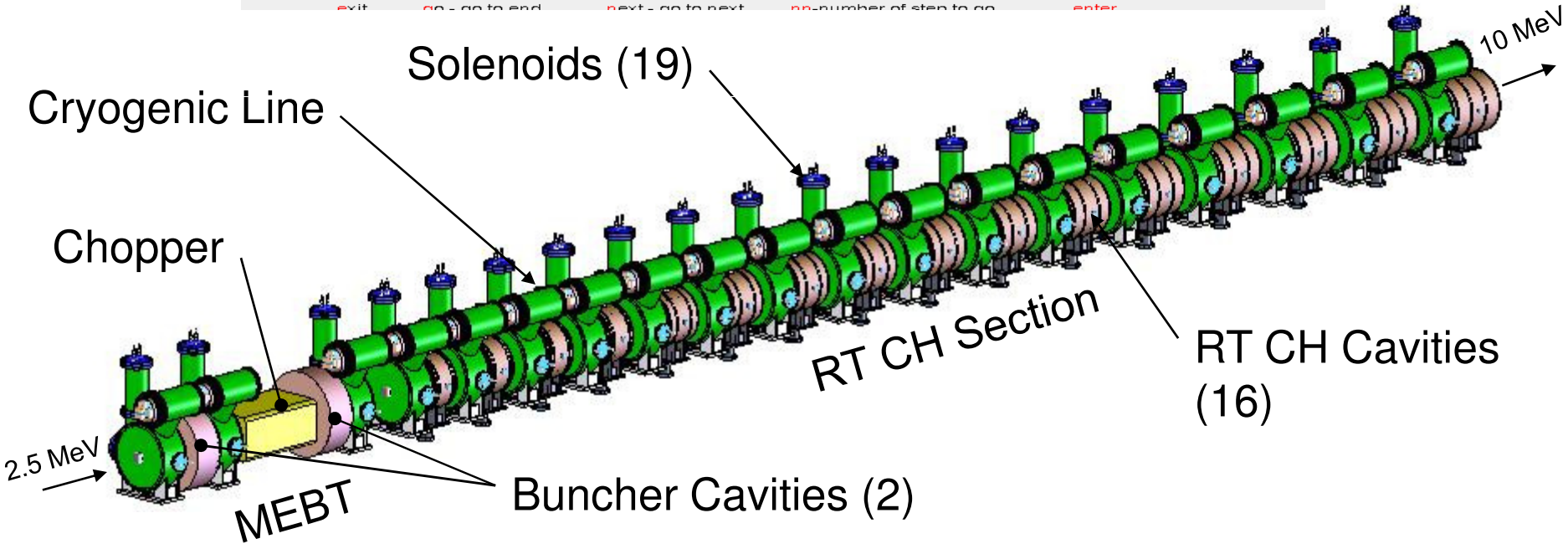






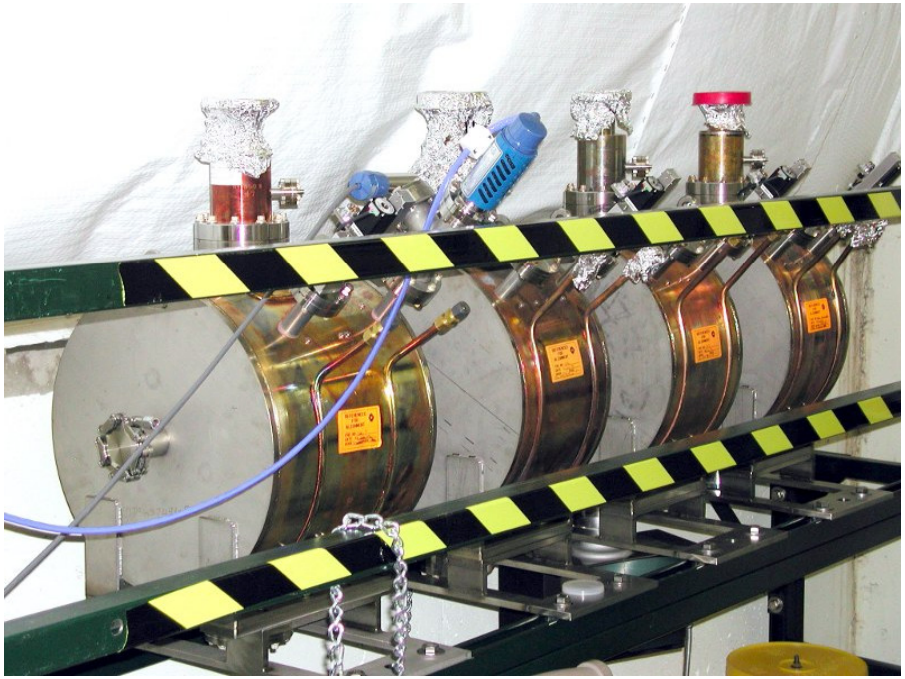
Room Temp Linac Section



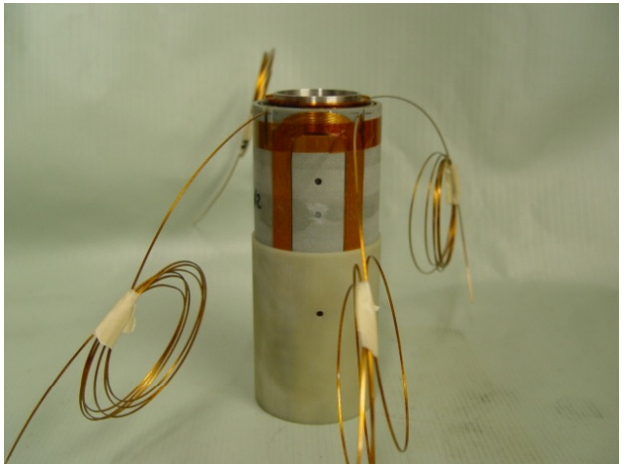


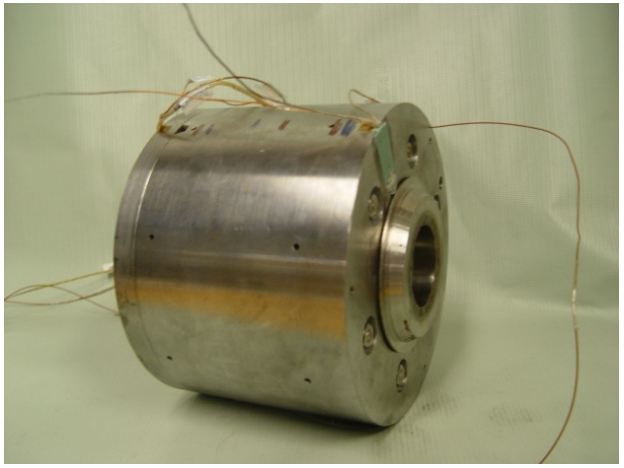
Linac Enclosure Under Construction Around Room Temp Section Girder

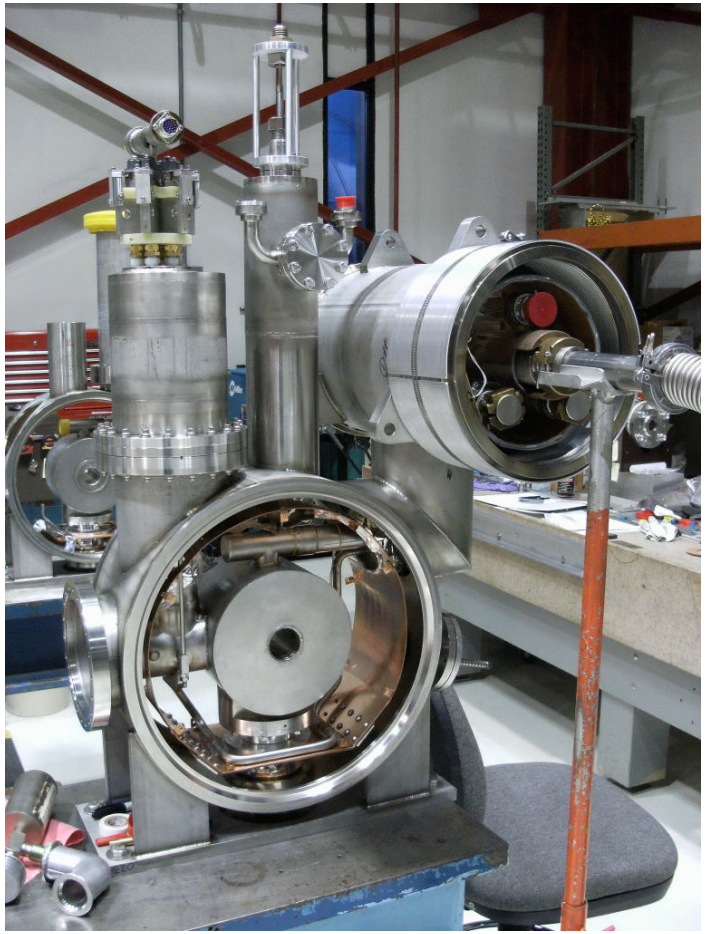
Tested RT-CH and Buncher Cavities



Room Temp Section Solenoid & Cryostat







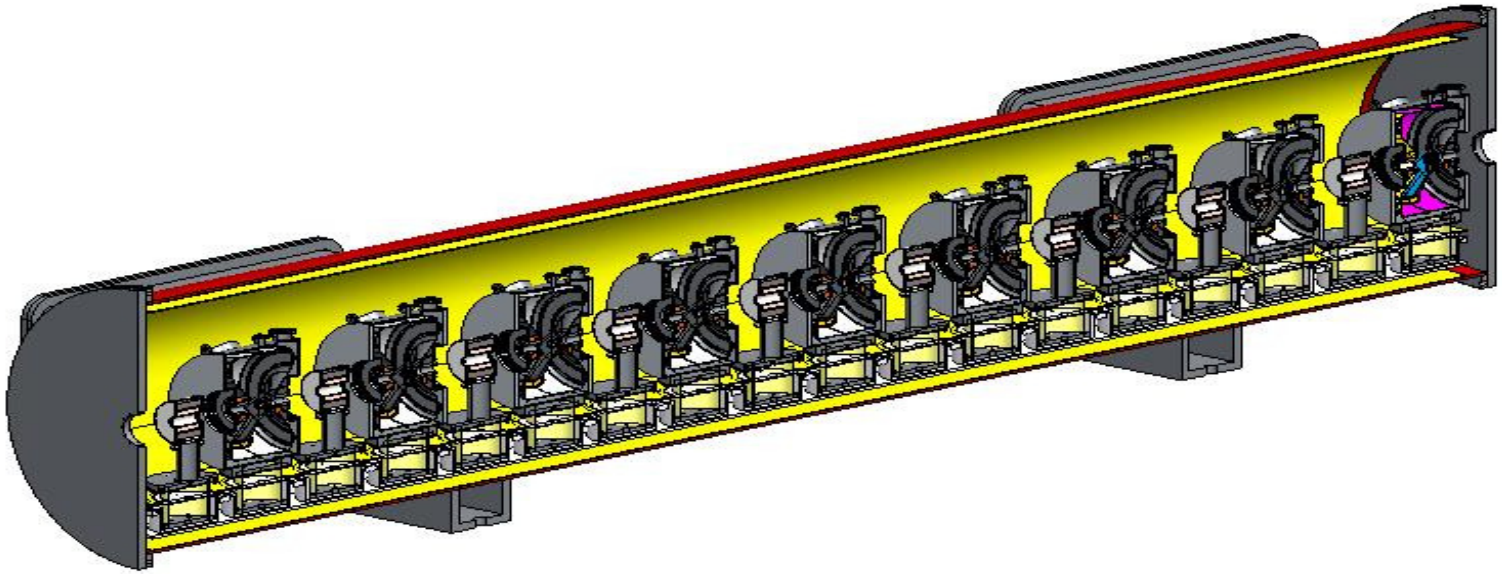
SSR1 Cavity – Bare and with Helium Vessel and Tuner

Spoke Cavity Test Cryostat

In MDB awaiting installation into test cavity cave

SSR1 Cryomodule Model

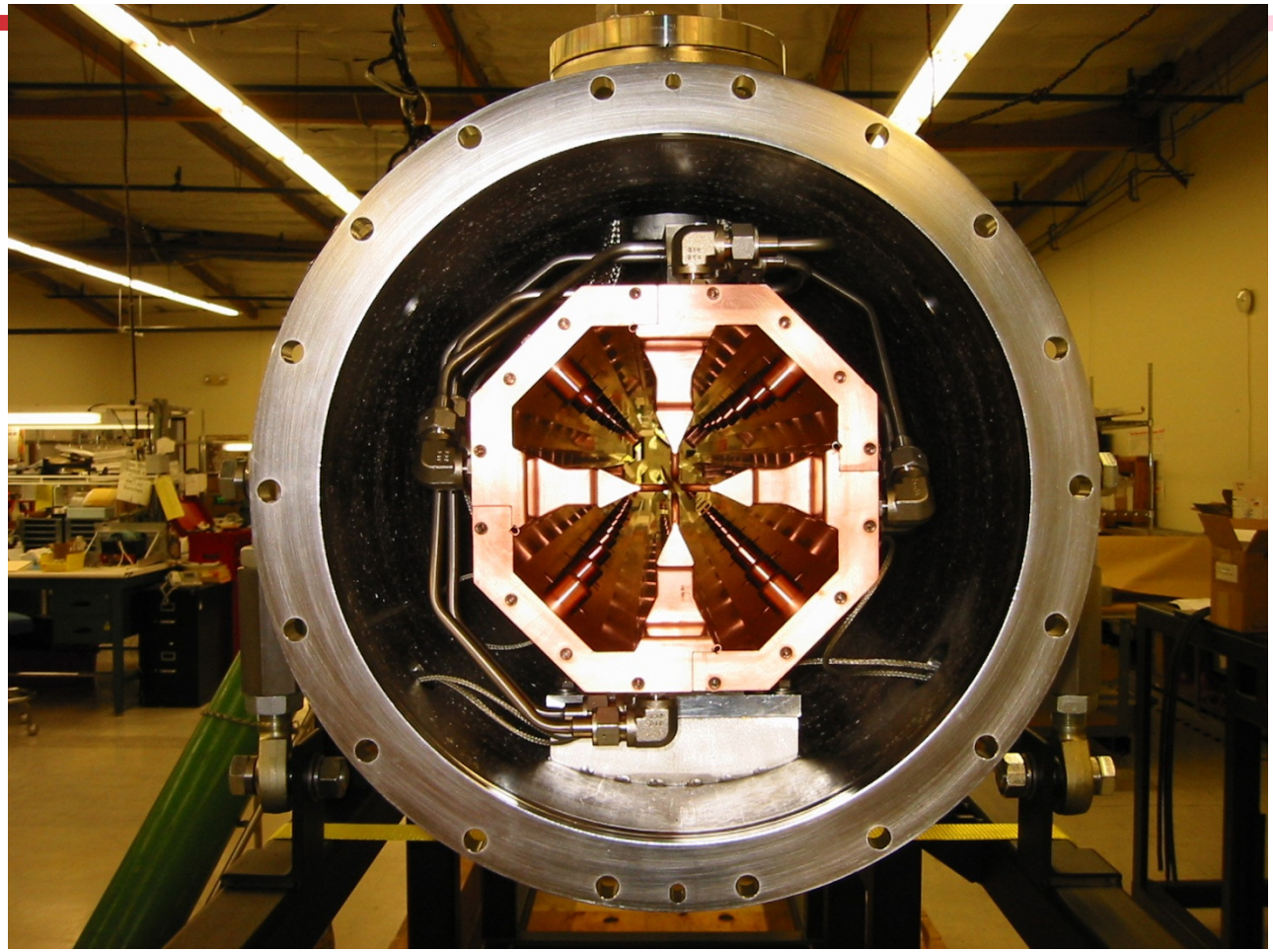
- Present conception of SSR1 Cryomodules
  - Contain 9 SSR1 cavities and 9 solenoids
  - Project X expects that these designs could be extended to SSR0 and SSR2 requirements



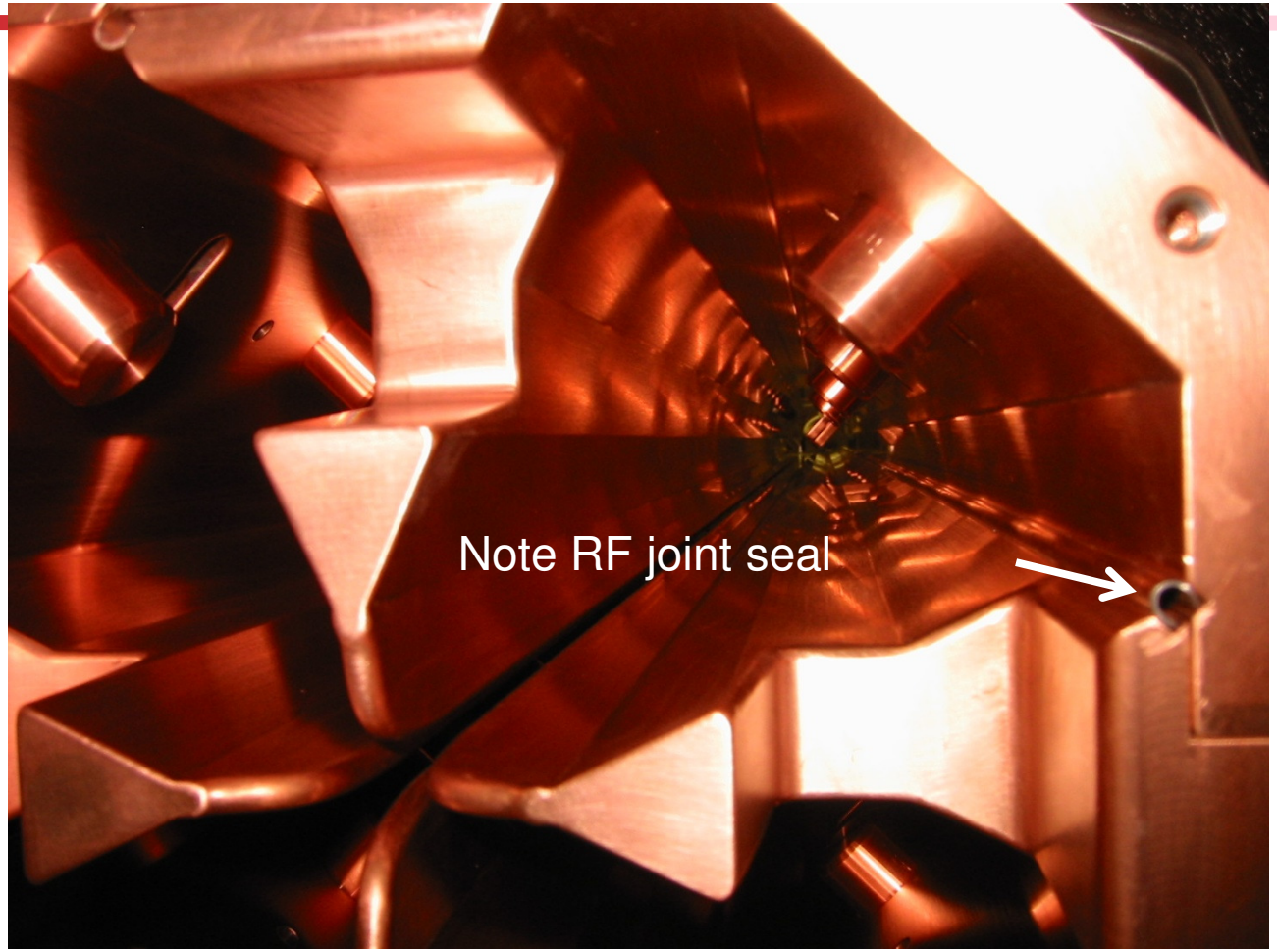
Possibility to Modify 325 MHz Test Cryostat for 2K Operation

- Estimated cryostat modification costs
  - New internal piping assembly: $17,000 (based on original system)
  - 4K to 2K heat exchanger: $15,000 (based on a similar exchanger purchased in the LHC program)
  - Control valve to heat exchanger: $6,000 (based on a similar valve purchased in the LHC program)
  - Misc: $2,000
  - Total: $40,000
  - EDIA: 6 FTE-months (combined engineering and drafting)
- There would also need to be a major modification/addition to the cryogenics supply system, feedbox, and transfer line.
  - No cost estimate yet for that but likely several times the cryostat modification costs
- Cryogenics plant, shared with elliptical cavity HTS, might also be strained to support large additional heat load for CW elliptical cavity testing

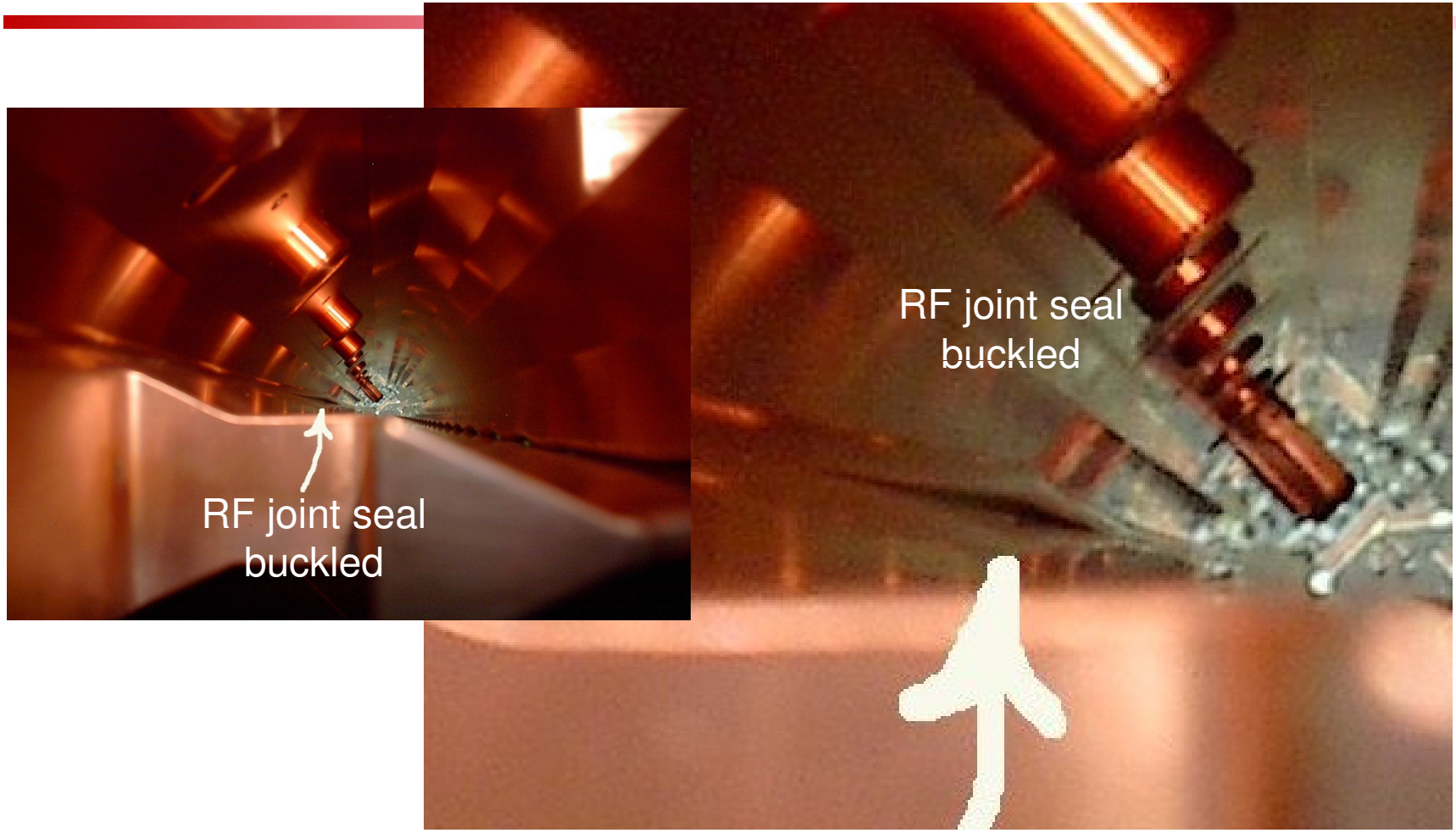
RFQ in Vacuum Tank



RFQ Close-up



RFQ RF Joint Failure



What is Clearly Beyond Current HINS Scope

- Spoke cavity or cryomodule development beyond SSR1
  - There is reason to believe that SSR1 is fast track to SSR0 and SSR2, but not necessarily to TSR
- CW ion source development
- CW RFQ development
- CW RF power system development
- SSR cryomodule operation at 2° K – the MDB cryogenics facility cannot support this

Current Component Fabrication and Design Activities

- RT Section Superconducting Solenoids
  - All cold masses are in-hand
  - Integrated BPM final dwgs and component procurement is yet to be done
  - Cryostat assembly is moving ahead with limited manpower
- SSR1 Superconducting Solenoids
- SSR1 RF Cavities
  - Remove from beam line to improve cooling water tubing seals
  - ~10 weeks from removal to re-installation
- SSR1 Cryomodule
- Cryogenics Systems
  - Continue construction of enclosure to support 10 MeV scope of operations
  - Complete with power and water utilities ~May?